



# PIER Energy-Related Environmental Research

Environmental Impacts of Energy Generation, Distribution and Use

## Modeling Fuel Cell Systems in Novel Distributed Energy Networks to Reduce Greenhouse Gas Emissions

**Contract #:** 500-02-004; MR-043-03

**Contractor:** Stanford University

**Contract Amount:** \$75,000

**Contractor Project Manager:** Professor Stephen Schneider

**Commission Project Manager:** Gina Barkalow

**Commission Contract Manager:** Beth Chambers

### The Issue

Greenhouse gas emissions are believed by climate scientists to be linked to significant global climate change, including record-breaking rainfall and flooding in California in 2006. Greenhouse gas emissions can be significantly reduced by improving the efficiency of energy production. On average, the U.S. currently wastes 68% of the available energy in fuel during electricity generation at power plants and an additional 28% during heat generation at boilers or furnaces.<sup>1</sup>

Stationary fuel cell systems are a promising technology that could fundamentally reduce the process inefficiencies in energy systems, and thereby yield a corresponding reduction in greenhouse gas emissions.<sup>2</sup> As small-scale power plants that can provide both electricity and heat directly to buildings, stationary fuel cell systems offer a practical way to combine the traditionally separate processes of electricity and heat generation, thus accruing the efficiency benefits of cogeneration<sup>3</sup> as well as the advantages of distributed power systems.<sup>4</sup> Stationary fuel cell systems could potentially provide complete energy services while dramatically reducing greenhouse gas emissions. In addition, fuel cell systems can be designed to produce extremely low levels of air pollutants.

Cogenerative fuel cell systems are scheduled to be built in California under the statewide Self-Generation Incentive Program and the Distributed Energy Strategic Plan. However, their optimal

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<sup>1</sup> A. V. da Rosa. 2005. *Fundamentals of Renewable Energy Processes*. Academic Press. See also the Energy Information Administration's *Annual Energy Review 1996* (U.S. Department of Energy, Washington DC, 1997), which estimates that 70% of available fuel energy going into electricity production is wasted.

<sup>2</sup> W. Colella. May 2003. "Modelling Results for the Thermal Management Sub-System of a Combined Heat and Power (CHP) Fuel Cell System (FCS)." *Journal of Power Sources* 118:129-49.

<sup>3</sup> Cogeneration is the coordinated production of electricity and heat, such that the waste heat from electricity generation is captured and used for space and water heating.

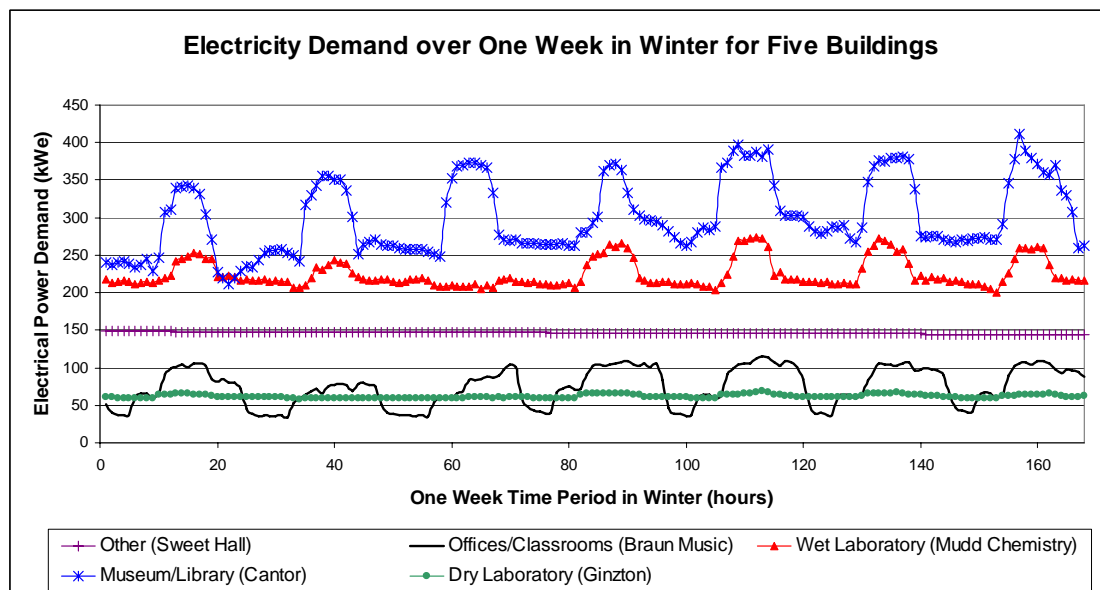
<sup>4</sup> Distributed power systems are small-scale power plants located close to the buildings they serve, as opposed to large, central power plants from which electricity must be transmitted over long distances. Distributed systems do not require high-voltage transmission lines to convey their power and therefore avoid energy losses due to the electrical resistance in the lines (about 3% of the original fuel energy).

implementation (operational profile, appropriate siting within a location) requires the ability to model the energy supply contributed by fuel cell systems to meet real-time energy demand.

Stationary fuel cell systems are typically operated in stand-alone mode, with a single fuel cell system serving a single building. By contrast, a networked fuel cell system can send its electricity via a local low-voltage distribution grid to surrounding buildings (not just a single building) and can convey its heat to multiple buildings via a local district heating network composed of water or steam pipes. Networking multiple fuel cell systems to serve several buildings (say, at a university or business park) could afford higher load factors<sup>5</sup>—which could improve system economics and lead to wider fuel cell system deployment in California, with associated greenhouse gas reductions.<sup>6</sup>

## Project Description

Funded by PIER’s Environmental Exploratory Grants Program, this research seeks to facilitate the optimal design of networks of stationary fuel cell systems. A simulation tool—referred to as the Maximizing Emission Reductions and Economic Savings Simulator (*MERESS*)—was developed to evaluate the electricity and heat supplied by networks of fuel cell systems against real-time electricity and heating demand in California buildings. The *MERESS* model uses real-time demand data, such as the load curves shown in Figure 1, as input data. Figure 1 shows the varying electricity consumption in five different types of California buildings over the course of one week.



**Figure 1.** Electricity consumption varies significantly in five different types of California buildings over the course of one week. Heating demand also varies greatly among buildings and over time. Load-following operation could potentially improve load factor—and therefore the economics—of fuel cell system installations.

<sup>5</sup> Load factor, or capacity utilization, is defined as the percentage of time a power plant is operating at its rated maximum power (its maximum capacity), and is a primary determinant of the cost of energy delivered.

<sup>6</sup> W. Colella, C. Niemoth, C. Lim, and A. Hein. February 2005. “Evaluation of the Financial and Environmental Feasibility of a Network of Distributed 200 kWe Cogenerative Fuel Cell Systems on the Stanford University Campus.” *Fuel Cells—From Fundamentals to Systems* 1: 148–166.

*MERESS* combines engineering models of fuel cell systems with energy demand data from California buildings. The model allows users to explore unique operating strategies typically overlooked by commercial industry, including networking, electrical vs. thermal load following, and variable heat-to-power ratios. *MERESS* directly evaluates trade-offs among three key goals: greenhouse gas reductions, energy cost savings for building owners, and sales revenue for fuel cell system manufacturers. *MERESS* enables quantitative analysis of how different ways of installing, controlling, and operating fuel cell systems can reduce greenhouse gas emissions from the power generation and heating sectors.

The research team deployed *MERESS* to evaluate different fuel cell system design, control, and installation configurations for their impacts on greenhouse gas emissions, energy cost savings for building owners, and sales revenue for fuel cell system manufacturers. The team evaluated these configurations under different scenarios for government incentives and carbon tax structures. The team also identified the most appropriate buildings for installing fuel cell systems to optimize either greenhouse gas reductions or energy cost savings, based on building load curves.

### **PIER Program Objectives and Anticipated Benefits for California**

This project offers numerous benefits and meets the following PIER program objectives:

- **Providing environmentally sound energy.** Detailed project results show that fuel cell systems, operated only as electricity generators with no heat recovery, could reduce California's greenhouse gas emissions from the electricity sector by up to 14%. By contrast, if implemented as cogenerators with high heat recovery and high capacity utilizations, fuel cell systems could reduce emissions from the combined electricity and heating sectors by up to 50%.<sup>7</sup> The simulation results from this project are critically needed to help (1) fuel cell developers to make design trade-offs, (2) fuel cell system engineers to prioritize design goals, and (3) California policymakers to develop appropriate strategies for more effective greenhouse gas reduction.
- **Providing reliable energy.** California requires a growing energy supply to serve its burgeoning population. Yet central power plants are difficult to site. Distributed power systems—i.e., small power sources that serve local loads—are a promising way to meet the rising demand for energy. The results of this research can assist in designing a more economical and environmentally sound distributed energy supply.

### **Results**

Model results show that the three competing goals—greenhouse gas reductions, lower energy costs to building owners, and enhanced sales revenue for fuel cell system manufacturers—may each be optimized with different installation and operating strategies, but that all three goals can be reasonably met with a single approach. For the specific scenarios evaluated, greenhouse gas emissions were minimized with stand-alone operation; energy costs for building owners were

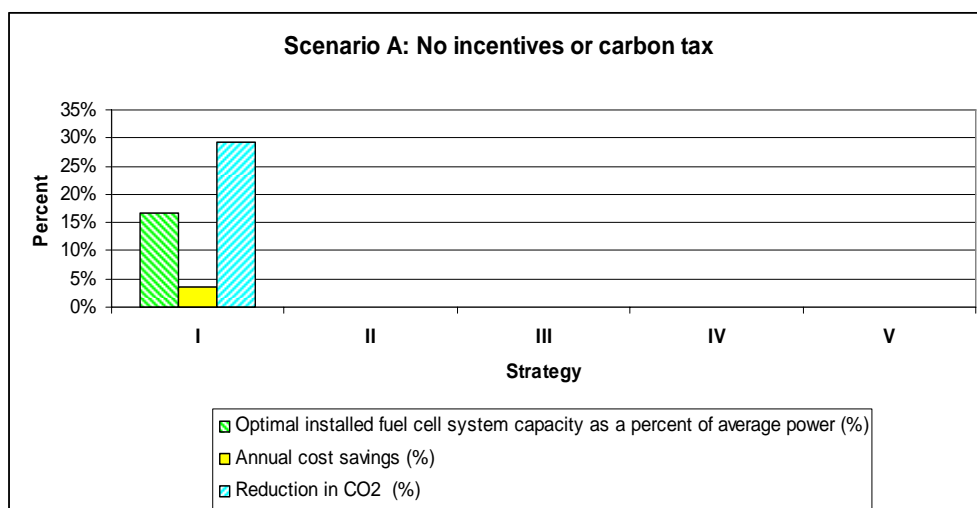
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<sup>7</sup> This back-of-the envelope cogeneration estimate compares the weighted average of electricity grid efficiency (U.S. national average is 32%) and boiler/furnace efficiency (average around 72%) to overall fuel cell efficiency (up to 95%, some claim, in cogeneration). Thus, if California's weighted electricity and heating fuel efficiency is 47% (or less), fuel cell systems could potentially double this fuel efficiency. Assuming similar fuel sources (natural gas) for all generators, one can estimate a greenhouse gas emission reduction of 50%. In practice, California's use of nuclear and renewable energy reduces the potential impact and its use of coal increases it.

minimized with networked operation; and revenues for manufacturers were maximized with basic, “plain vanilla” fuel cell system designs with a fixed heat-to-power ratio.

The electricity and heating load curves of individual buildings were extremely important in determining the economics and greenhouse gas emission reductions from an installation. Although no particular building type stood out as consistently achieving the highest emission reductions and cost savings, certain building load curves were clear winners (e.g., wet labs such as chemistry labs).

The final report identifies effective public policies to promote greenhouse gas reductions through fuel cell system deployment. Policies targeting installation/operational configurations may be more successful in reducing greenhouse gas emissions than carbon-related incentives.



*Figure 2. Under a scenario with no government incentives, the best option for the environment, building owners, and fuel cell system manufacturers is an avant-garde installation strategy (Strategy I), in which the fuel cell systems are networked and follow the electrical load with a variable heat-to-power ratio. Under this strategy, fuel cell systems are economical for building owners even without government incentives.*

## Final Report

The final report for this project can be downloaded from [www.energy.ca.gov/2008publications/CEC-500-2008-030/CEC-500-2008-030.PDF](http://www.energy.ca.gov/2008publications/CEC-500-2008-030/CEC-500-2008-030.PDF).

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